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# The Effect of Foliar Fertilization on Soybean Yield and Leaf Necrosis

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THE EFFECT OF FOLIAR
FERTILIZATION ON SOYBEAN
YIELD AND LEAF NECROSIS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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# INTRODUCTION

The soybean (*Glycine max* (L.) Merrill) is a very important world crop. The seed is rich in both protein and oil, making it a valuable human food resource. Many scientists believe that there are physiological barriers preventing increased soybean yields. Any agronomic discovery that would consistently increase soybean yields would be important to world food production.

One possible yield barrier in soybeans concerns the mineral nutrition of the plant during the seed-filling stages of growth. During this period of growth, translocation of N, P, K, and S from the plant foliage to the developing seed occurs, accompanied by a virtual cessation of uptake of these elements. The possibility of a yield increase from the foliar application of these elements during this period of growth has been suggested.

Soybean yield increases of over 1500 kg/ha (23 bu/ac) have been recorded in Iowa from the application of N, P, K, and S in the form of foliar fertilizers. Preliminary research with foliar fertilizers in South Dakota showed no yield response and considerable leaf necrosis. Little is known about the effect of foliar fertilizer-induced leaf necrosis on soybean yields. A better understanding is also needed of what weather conditions minimize this leaf necrosis.

The purpose of this study was threefold: (1) to determine if foliar fertilization can increase soybean yields under South Dakota growing conditions, (2) to determine the effect of foliar fertilizer-induced leaf necrosis on soybean yield, and (3) to quantify the relationship between foliar fertilizer-induced leaf necrosis and the weather conditions at the time of fertilizer application.

# REVIEW OF LITERATURE

The processes of nutrient uptake and translocation which occur during the latter stages of soybean growth will be discussed in the first portion of this review. Previous research of soybean foliar fertilization will be covered in the second portion. This will be followed by a review of the research conducted on the effects of climate on foliar fertilizer-induced leaf necrosis. Stage of growth designations will follow those proposed by Fehr, et al. (12). Stage of growth descriptions are found in Appendix Table A.

## I. Mineral Nutrition of Soybeans During the Seed-Filling Stages of Growth

### Nitrogen

Translocation of nitrogen (N) from all soybean plant parts to the developing seed has been observed by many researchers (5, 9, 11, 16, 17, 19, 20, 21, 32, 33, 34). Hanway and Weber (19) estimated that half of the N in the soybean seed came from direct translocation from other plant parts. The other half of the N came from plant uptake occurring between growth stages R4 and R5.

Uptake of N slows considerably after growth stage R5. This phenomena has been observed by several researchers (16, 17, 19, 22, 23). Streeter (31) recorded that soybean nodules lose their color after growth stage R5, an indication that N fixation has ceased (1).

Lawn and Brun (22) demonstrated that a marked decrease in N fixation by soybean plants, as measured by acetylene reduction, begins at growth stage R5. They attributed this decline in N fixation to a reduction in the quantity of photosynthate supplied to the roots as the pods and seeds become the dominant photosynthate sink. They concluded that N fixation alone is not sufficient to satisfy the N demands of the developing seeds.

Lathwell and Evans (21) showed that N translocation from the plant foliage to the developing seed did not supply enough N for maximum yields of soybeans growing outdoors in sand pots. Nitrogen had to be supplied to the soybeans from nutrient solutions throughout the seed-filling stages for maximum yields. Similar results were obtained by Streeter (32).

Several authors (9, 17, 22, 23) have suggested that soybean production is being limited by the process of N uptake and translocation that occur during the seed-filling stages of growth.

### Phosphorus and Potassium

The patterns of uptake and translocation of phosphorus (P) and potassium (K) are vitually identical to the patterns of N uptake and translocation, according to

Hanway and Weber (19), and Hanway (17). Translocation of P and K from the plant foliage to the developing seed occurs between growth stages R5 and R8, accompanied by a virtual cessation of P and K uptake.

### Sulfur and Minor Elements

Dunphy (8) and Hanway (17) demonstrated that sulfur (S) uptake and translocation is almost identical to the patterns of N, P, and K uptake and translocation. The developing seeds deplete the supply of S in the plant foliage. Hanway (17) also showed that the plant foliage supplies of calcium, magnesium, sodium, manganese, zinc, copper, and boron are not severely depleted during seed-fill. This indicates that these minor elements behave differently than N, P, K, and S.

The depletion of N, P, K, and S, in the soybean foliage accompanied by a virtual cessation of the uptake of these elements during seed-fill indicates that soybean yields may be increased through late-season application of foliar fertilizers containing N, P, K, and S.

## II. Foliar Fertilization of Soybeans

Several studies (3, 6, 24, 30, 39) have shown no response of soybeans to foliar applications of N or P. Soybeans have given yield responses to minor element sprays (2, 7, 26, 27, 35), but only when there was a marked soil deficiency of available forms of the given minor element.

Garcia L. and Hanway (14) theorized that if soybean yields were being limited by the translocaiton of N, P, K, and S to the developing seeds, then soybeans should respond to late-season foliar applications of these elements.

The spray solutions tested by Garcia L. and Hanway contained N, P, K, and S in a 10:1:3:0.5 elemental ratio, respectively. This corresponds to the ratios of these elements in a typical soybean seed (28). Their results substantiated their hypothesis. Yield increases of up to 1570 kg/ha were obtained. Little response was obtained if any of the four elements were left out. Increasing the relative proportion of any of the four elements in the spray solution had no added influence on yield.

The yield increases recorded by Garcia L. and Hanway were obtained under high yield potential conditions (yields up to 5340 kg/ha were recorded). These yield potentials are much higher than exist in South Dakota, where yields of 1100-2100 kg/ha are common (4). Research was needed to determine if the techniques successful for Garcia L. and Hanway would promote soybean yield increases in South Dakota.

## III. Foliar Fertilizer-Induced Leaf Necrosis

The application of fertilizer solutions to plant foliage has long been linked to necrosis of leaf tissues. Leaf necrosis resulting from foliar applications of urea solutions have been widely reported (6, 10, 13, 24, 30, 39). Sucrose (table sugar) has been found to reduce urea toxicity in foliar sprays (6, 10, 24, 36). Urea is a major constituent of the foliar fertilizer sprays tested by Garcia L. and Hanway (14).

Considerable leaf necrosis has been reported by researchers in several states attempting to duplicate Garcia L. and Hanway's results (15, 18). No quantification of the relationship between foliar fertilizer-induced leaf necrosis and soybean yield has been found in the literature.

Weather conditions at the time of spray application influence the amount of leaf necrosis induced by the fertilizer sprays, according to Hanway (18). He observed that foliar fertilizer-induced leaf necrosis seemed highest when applications were made during the middle of the day. Hanway also indicated that urea was the substance responsible for the leaf necrosis induced by spray solutions formulated according to the guidelines given by Garcia L. and Hanway (14).

Some relationships between weather conditions and rate of absorption of foliar-applied nutrients have been noted. Volk and McAuliffe (37), working with tobacco leaves, recorded that absorption of $N^{15}$ labeled urea was three to ten times faster at night than during the day. The absorption rate was also three times higher in the morning than in the afternoon. Absorption of urea continued at a slow rate even after the urea solution dried to a solid deposit on the leaf. Absorption rate was negatively correlated to temperature, and positively correlated to relative humidity.

Similar results were recorded by Long, et al. (23), and Tuebner, et al. (36), working with the application of radioactive isotopes of P, K, and rubidium on bean and tomato leaves.

Webster (38) stated that total magnesium absorption by apple leaves was poorly correlated to temperature or humidity at application time. Total absorption was correlated ($R^2$=.86) to a humidity/temperature index which considered weather conditions over a 24 hour period after spraying.

Rate of absorption must not be the only factor controlling the amount of leaf necrosis obtained from foliar fertilization. Volk and McAuliffe (37) reported minimum rates of urea absorption during the times of day when

Hanway (18) observed maximum amounts of necrosis. Hanway's assessment of the effect of weather on foliar fertilizer-induced leaf necrosis was not based on quantitative measurement of leaf necrosis. No quantification of the relationship between weather conditions (temperature, humidity, wind speed, etc.) and foliar fertilizer-induced leaf necrosis has been found in the literature.

A summary of this review points out several research needs. Processes within the soybean plant show the potential for yield response to N, P, K, and S foliar fertilization during seed-fill.

Large increases in yield due to foliar fertilization with N, P, K, and S have been obtained under high yield conditions. It is not known whether soybeans will respond to N, P, K, and S foliar fertilization under the lower yield potentials that exist in South Dakota.

Leaf necrosis has been reported as a result of foliar fertilization of soybeans. Weather conditions have been indicated as a factor in the amount of necrosis induced. Rate of nutrient absorption has been related to weather conditions, but no quantification of the relationship between weather conditions and leaf necrosis has been found in the literature. The relationship between foliar fertilizer-induced leaf necrosis and soybean yield has not been found in the literature.

Experiments were established in the 1976 and 1977 growing seasons with three objectives. The major emphasis was to determine if foliar fertilization of soybeans with N, P, K, and S solutions during seed-fill would produce a yield response. Another objective was to determine what relationships could be quantified between weather conditions and foliar fertilizer-induced leaf necrosis. The third objective was to investigate the relationship between foliar fertilizer-induced leaf necrosis and soybean seed yield.

# MATERIALS AND METHODS

## General

Eleven field experiments were conducted during the 1976 and 1977 growing seasons to evaluate the effects of foliar fertilization on soybean yield and leaf necrosis. The cultural practices used in each experiment are documented in Table 1. Soil classification and soil test results are presented in Table 2. Climatic data for the two growing seasons are presented in Appendix Table B.

The foliar fertilizer solutions used in all experiments had an elemental analysis of 10% N, 1% P, 3% K, and 0.6% S. The sources of these nutrients were: urea, potassium polyphosphate, and potassium sulfate, in all experiments except 77-6. The sources of nutrients used in experiment 77-6 will be dealt with in the discussion of the individual experiments. The surfactant used was 0.1% Tween 80. All experiments were seeded at 67 kg seed/ha.

All foliar fertilizer solutions were applied to the soybean foliage with a high clearance, self-propelled sprayer in 1976. A hand sprayer was used at the Brookings County sites in 1977, and a four-row bicycle wheel sprayer was used in the Clay County sites in 1977. Application pressure was 275 KPa.

Table 1. Some characteristics of the foliar fertilization experiments.

| Experiment Designation | Location* | County | Cultivar | Row Spacing (cm) | Planting Date | Herbicide | Irrigation |
|---|---|---|---|---|---|---|---|
| 76-1 | JVRAEC | Spink | Wells | 91 | 2 June 1976 | Amiben | No |
| 76-2 | JVRAEC | Spink | Wells | 91 | 2 June 1976 | Amiben | Yes |
| 76-3 | SSDRAEC | Clay | NK 1474 | 76 | 28 May 1976 | Lasso II | No |
| 76-3 | Hunter | Clay | Corsoy | 76 | 1 June 1976 | Lasso II | Yes |
| 77-1-3 | Agron. F. | Brookings | Hodgson | 76 | 16 May 1977 | Lasso II | No |
| 77-4-6 | SSDRAEC | Clay | Corsoy/ Chipp. 64 | 76 | 1 June 1977 | Lasso II | No |
| 77-7 | SSDRAEC | Clay | Calland<br>Corsoy<br>Evans<br>Harcor<br>Hodgson<br>Swift<br>Wayne<br>Wells | 76 | 23 May 1977 | Lasso II | No |

*JVRAEC= James Valley Research and Extension Center
SSDRAEC= Southeast South Dakota Research and Extension Center

Table 2. Soils information from the experimental areas.

| Experiment Designation | County | Series | Classification | Soil Test Results* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | O.M. (%) | P (kg/ha) | K (kg/ha) | Salts mmho/cm | pH |
| 76-1 | Spink | Beotia | Pachic Udic Haploboroll fine-silty, mixed | 1.9<br>VL | 59<br>VH | 450<br>VH | 0.69<br>NS | 7.5 |
| 76-2 | Spink | Beotia | Pachic Udic Haploboroll fine-silty, mixed | 2.6<br>M | 34<br>H | 460<br>VH | 0.50<br>NS | 7.2 |
| 76-3 | Clay | Egan | Udic, Haplustoll, fine-silty, mixed, mesic | 2.8<br>M | 24<br>M | 470<br>VH | 0.70<br>NS | 6.4 |
| 76-4 | Clay | Dempster | Udic Haplustoll, sandy over sandy skeletal, mesic | 4.0<br>VH | 84<br>VH | 430<br>VH | 0.53<br>NS | 6.8 |
| 77-1-3 | Brookings | Vienna | Udic Haploboroll fine-loamy, mixed | 4.0<br>VH | 62<br>VH | 530<br>VH | 0.38<br>NS | 7.0 |
| 77-4-7 | Clay | Viborg | Pachic Haplustoll, fine-silty, mixed, mesic | 3.7<br>H | 34<br>H | 680<br>VH | 1.7<br>NS | 6.6 |

*VL= very low
M= medium
H= high
VH= very high
NS= non-saline

Foliar fertilizer applications, in all experiments, began at growth stage R5 (12). Documentation of the application dates, number of replications, experimental design, and other data pertinent to each individual experiment can be found in Appendix Table C. Experiments 76-3 and 76-4 were harvested with a combine. All other experiments were harvested by hand and threshed with a plot thresher. Each experiment will be discussed in greater detail.

Experiments conducted in 1976

Experiments 76-1 and 76-2 were located at the James Valley Research and Extension Center, 10 km east of Redfield, South Dakota. The two experiments were identical, except that 76-2 was surface irrigated. Foliar fertilizer was applied at 0 and 211 kg/ha at both growth stages R5 and R6.

Experiments 76-3 and 76-4 were located on the Southeast South Dakota Research Farm and on the Don Hunter farm, respectively. Both are in Clay County.

These two experiments were identical to each other, except that experiment 76-4 was sprinkler irrigated twice during the growing season. Foliar fertilizer was applied at the rates of 0 and 211 kg/ha at each growth stage R5, R6, R6.5, and R7.5. Insufficient irrigation water was available to meet the needs of the crop in experiment 76-4.

The effect of foliar fertilization on soybean yield was the only emphasis of the 1976 field experiments. Due to problems encountered with leaf necrosis in 1976, additional variables were added to the experiments established in 1977.

Experiments conducted in 1977

Experiment 77-1 was designed to detect the influence of foliar fertilization on soybean yields both with and without sucrose. Fertilizer rates of 0, 263, and 395 kg/ha and sucrose rates of 0 and 56 kg/ha were combined in a 3 x 2 factorial. All six fertilizer treatments were applied at both the R5 and R6 growth stages.

Leaf necrosis was a problem in 1976. Experiment 77-2 was designed to measure the influence of foliar fertilizer-induced leaf necrosis on soybean yield. Foliar fertilizer was applied at 0, 132, 263, 395, 526, 658, 790, 921, and 1053 kg/ha at growth stage R5. One week after application, leaf samples were taken in the following manner: 8-10 random plants in each plot were severed at the fourth node from the top of the plant. The leaves from this upper portion were then severed from the petioles, pressed, and randomly divided into two subgroups per plot. Total leaf area and necrotic leaf area was measured with a 0.5 x 0.5 cm dot grid.

Informal observation in 1976 suggested that the amount of leaf necrosis was influenced by the climatic conditions at application time. Experiment 77-3 was designed to quantify this relationship. Foliar fertilizer was applied at 0, 263, and 526 kg/ha at 0600, 0800, 1000, 1400, 1600, 1800, and 2000 Central Daylight Time (C.D.T.) on 10 August and 11 August 1977. Leaves were sampled and measured for leaf necrosis according to the procedure listed in experiment 77-2. Climatic data was taken from the Agronomy Farm weather station. This data included: wind speed, air temperature, dew point temperature, and incoming solar radiation.

Four experiments were conducted at the Southeast South Dakota Research Farm in 1977. Experiment 77-4 was designed to test the response of soybeans to foliar fertilization with and without sucrose. Foliar fertilizer rates of 0, 263, and 526 kg/ha were combined with sucrose rates of 0, 28, and 56 kg/ha in a 3 x 3 factorial. All nine treatments were applied at both the R5 and R6 growth stages.

Experiment 77-5 was designed to determine, as accurately as possible, if foliar fertilization could influence soybean yields. A small number of treatments and a large number of replications were used to give better error control. Foliar fertilizer was applied at the rates of

0 and 263 kg/ha at growth stages R5 and R6. Twelve replications were used.

Three identical solutions of different nutrient sources were tested in experiment 77-6, to determine if any of the three could promote a soybean yield increase. All three solutions had a 10% N, 1% P, 3% K, and 0.6% S analysis. Solution 1 used the same fertilizer sources used in the other experiments. Solution 2 was composed of urea, ammonium sulfate, potassium nitrate and ammonium polyphosphate. The third solution contained urea, ammonium polyphosphate, ammonium sulfate, and potassium chloride. Each solution was applied at the rates of 0, 263, and 395 kg/ha at both growth stages R5 and R6.

Eight cultivars were foliar fertilized in experiment 77-7 to measure if there was a difference in response due to cultivar. The cultivars were, from earliest to latest maturity: Evans, Swift, Hodgson, Corsoy, Harcor, Wells, Wayne, and Calland. Varieties were used as whole plots and fertilizer treatments as subplots. One half of each plot received 263 kg/ha of foliar fertilizer at growth stages R5, R6, and R7. The other half of the plot received no foliar fertilizer.

# RESULTS AND DISCUSSION

The results and discussion will be divided into three sections: (1) yield increase experiments of 1976, (2) yield increase experiments of 1977, and (3) foliar fertilizer-induced leaf necrosis experiments of 1977.

## Yield Increase Experiments of 1976

The effects of foliar fertilizer on soybean yields in experiments 76-1 (dryland) and 76-2 (irrigated), located at the James Valley Research and Extension Center, are presented in Table 3. Any variations in yield between foliar fertilized treatments and the check were less than the Least Significant Difference (L.S.D.) at the 0.5 level.

Moisture and heat stress were constant problems at this site and all other experimental sites in 1976 (Appendix Table B). Yields were limited by moisture stress in all experiments conducted in 1976. Experiment 76-2 could only be irrigated once, due to low water supplies. The quantity of water added in this experiment was insufficient to supply the needs of the crop.

Some leaf necrosis was produced by the foliar sprays. Approximately 10-15% of the leaf area (visual rating) was affected by each of the two foliar fertilizer applications.

Table 3. Effect of foliar fertilization on soybean yields, Spink County, 1976.

| Rate of Foliar Fertilizer Applied at Growth Stage: R5 (kg/ha) | R6 (kg/ha) | Soybean yield in Experiment: 76-1 (Dryland) (kg/ha) | 76-2 (Irrigated) (kg/ha) |
|---|---|---|---|
| 0 | 0 | 1164 | 2301 |
| 211 | 0 | 1103 | 2200 |
| 0 | 211 | 1257 | 2186 |
| 211 | 211 | 1090 | 2274 |
| | L.S.D.(.05)= | 264ns | 244ns |
| | C.V.= | 13.4% | 11.9% |

Foliar fertilization had no significant positive influence on soybean yields in experiment 76-3 and 76-4 (Table 4). These experiments were located within seven km of each other in northern Clay County. Many treatments receiving more than one foliar application had significantly lower yield than the check in experiment 76-3.

Experiment 76-4 was irrigated twice. The soybeans in this experiment produced a large amount of vegetative growth. Yields were below average in this experiment, due to the high temperatures and disicating winds that occurred during flowering and pod-set. Lodging was a problem in this experiment, and yields were more variable, that is, there was a higher experimental error for experiment 76-4 than in other experiments.

Table 4. Effect of foliar fertilization on soybean yields, Clay County, 1976.

| Rate of Foliar Fertilizer Applied at Growth Stage R5 (kg/ha) | R6 (kg/ha) | R6.5 (kg/ha) | R7.5 (kg/ha | Soybean Yield in Experiment: 76-3 (Dryland) (kg/ha) | 76-4 (Irrigated) (kg/ha) |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1378 | 1156 |
| 211 | 0 | 0 | 0 | 1163* | 1465 |
| 0 | 211 | 0 | 0 | 1210 | 1304 |
| 0 | 0 | 211 | 0 | 1230 | 1613 |
| 0 | 0 | 0 | 211 | 1236 | 1270 |
| 211 | 211 | 0 | 0 | 1176* | 995 |
| 211 | 0 | 211 | 0 | 1223 | 1310 |
| 211 | 0 | 0 | 211 | 1223 | 1539 |
| 0 | 211 | 211 | 0 | 1230 | 1196 |
| 0 | 0 | 211 | 211 | 1183* | 1599 |
| 0 | 211 | 0 | 211 | 1270 | 1095 |
| 211 | 211 | 211 | 0 | 995* | 820 |
| 211 | 211 | 0 | 211 | 1156* | 1183 |
| 211 | 0 | 211 | 211 | 1216 | 1438 |
| 0 | 211 | 211 | 211 | 1183 | 948 |
| 211 | 211 | 211 | 211 | 1203* | 1015 |
| | | | L.S.D.(.05)= | 173 | 462ns |
| | | | C.V.= | 10.0% | 22.2% |

*Significantly lower than the check at the .05 level.

Leaf necrosis was a problem in experiments 76-3 and 76-4. Foliar fertilizer applied at growth stage R5 produced 25% leaf area necrosis (visual rating). Applications made at other stages of growth produced from 5-10% leaf area necrosis.

Soybean yield potentials were low due to drought and high temperatures in 1976, and any yield benefit possible from foliar fertilization was masked by the drought conditions.

Field notes taken during the 1976 growing season indicated the existence of a relationship between the time of day that the foliar fertilizer application was made and the amount of leaf necrosis produced by foliar fertilization. Leaf necrosis appeared to be the greatest from foliar fertilizer applications made during the late morning and early afternoon.

Yield Increase Experiments of 1977

Environmental conditions were favorable for soybean production in 1977. There was ample late-season precipitation. Temperatures for August, the main month of foliar fertilizer application, were lower in 1977 than in 1976. (Appendix Table B).

The effects of foliar fertilization and sucrose on soybean yields and leaf necrosis are presented in Table 5 for experiment 77-1 (Agronomy Farm), and Table 6 for experiment 77-4 (Southeast Farm). Foliar fertilization had no significant effect on soybean yields in either experiment.

Sucrose had no effect on leaf necrosis in experiment 77-1. Leaf necrosis was proportional to fertilizer rate. The amount of leaf necrosis (visual rating) shown in Table 6 produced by 1052 kg/ha of foliar fertilizer was significantly reduced by dissolving 112 kg/ha of sucrose in the spray solution.

Table 5. Effects of sucrose and foliar fertilization on soybean yield and leaf necrosis, Brookings County, 1977.

| Total Nutrient Application*: Foliar Fertilizer (kg/ha) | Sucrose (kg/ha) | Soybean Yield (kg/ha) | Leaf Area Necrosis (%) |
|---|---|---|---|
| 0 | 0 | 2251 | 0 |
| 0 | 112 | 2386 | 0 |
| 526 | 0 | 2244 | 5 |
| 526 | 112 | 2244 | 5 |
| 790 | 0 | 2271 | 10 |
| 790 | 112 | 2264 | 10 |
| | L.S.D.(.05)= | 257ns | |
| | C.V.= | 6.0% | |

*Total of two equal applications made at growth stages R5 and R6.

Table 6. Effects of sucrose and foliar fertilization on soybean yield and leaf necrosis, Clay County, 1977.

| Total Nutrient Application*: Foliar Fertilizer (kg/ha) | Sucrose (kg/ha) | Soybean Yield (kg/ha) | Leaf Area Necrosis (%) |
|---|---|---|---|
| 0 | 0 | 1855 | 0 |
| 0 | 56 | 1740 | 0 |
| 0 | 112 | 2097 | 0 |
| 526 | 0 | 1861 | 12 |
| 526 | 56 | 1841 | 12 |
| 526 | 112 | 1767 | 8 |
| 1052 | 0 | 1572 | 32 |
| 1052 | 56 | 1606 | 28 |
| 1052 | 112 | 1653 | 18 |
| | L.S.D.(.05)= | 314ns | 6 |
| | C.V.= | 8.6% | 3.2% |

*Total of two equal applications made at growth stages R5 and R6.

Foliar fertilization stimulated a statistically significant (.05 level) yield response in experiment 77-5 (Table 7), which was located at the Southeast Farm. The size of this increase (215 kg/ha or 3.2 bu/ac) was approximately 10% of the check yield, which was substantially smaller than the magnitude of the yield increases obtained by Garcia L. and Hanway (14). Foliar fertilizer-induced leaf necrosis was negligible in this experiment. Leaf necrosis was considered to be negligible if less than 5% of the leaf area was affected.

Table 7. Effect of foliar fertilizer on soybean yield, Clay County, 1977.

| Rate of Foliar Fertilizer Applied at Growth Stage: R5 (kg/ha) | R6 (kg/ha) | Soybean Yield (kg/ha) |
|---|---|---|
| 0 | 0 | 2003 |
| 263 | 0 | 2218* |
| 0 | 263 | 2009 |
| 263 | 263 | 2083 |
| | L.S.D.(.05)= | 155 |
| | C.V.= | 9.0% |

*The yield from this treatment is significantly higher than the check at the .05 level.

The effects of three fertilizer solutions, made up through the use of different nutrient sources, on soybean yields in experiment 77-6 (Southeast Farm) are presented in Table 8. No yield benefit was gained from the application of any of the three fertilizer solutions.

Levels of leaf necrosis produced by foliar fertilization were small, and no difference in the burn producing tendencies of the three solutions could be detected. The lower fertilizer rate produced negligible leaf necrosis and the higher rate produced less than 10% leaf necrosis by visual rating.

Table 8. Effect of three foliar fertilizer solutions on soybean yields, Clay County, 1977.

| Fertilizer Solution** | Total Fertilizer Application* (kg/ha) | Soybean Yield (kg/ha) |
|---|---|---|
| - | 0 | 1996 |
| Solution 1 | 526 | 2211 |
| Solution 2 | 526 | 2157 |
| Solution 3 | 526 | 2197 |
| Soluiton 1 | 790 | 2003 |
| Solution 2 | 790 | 2016 |
| Solution 3 | 790 | 2090 |
| | L.S.D.(.05)= | 316ns |
| | C.V.= | 8.6% |

*Sum of two equal applications made at growth stages R5 and R6.
**Analysis of all solutions was: 10% N, 1% P, 3% K, 0.6% S. Solution 1: urea, potassium polyphosphate, potassium sulfate. Solution 2: urea, ammonium sulfate, ammonium polyphosphate, potassium nitrate. Solution 3: urea, ammonium sulfate, ammonium polyphosphate, potassium chloride.

The effect of foliar fertilization on the yield of seven soybean cultivars in experiment 77-7 (Southeast Farm) is shown in Table 9. Spotty seedling emergence due to soil crusting increased the experimental error of this trail. One cultivar, Evans, had to be abandoned due to poor seedling emergence.

The differences in yields in experiment 77-7 were not signigicant at the .05 level. One cultivar, Wells, when foliar fertilized, yielded 370 kg/ha (5.5 bu/ac) more than its untreated check. This yield increase was the largest observed in this study, and was almost large enough to be declared statistically significant at the .05 level.

Table 9. Effect of foliar fertilization on the yield of seven soybean cultivars, Clay County, 1977.

| Cultivar | Soybean Yield: Foliar Fertilized* (kg/ha) | Not Foliar Fertilized (kg/ha) | Difference (kg/ha) |
|---|---|---|---|
| Swift | 1688 | 1554 | +134 |
| Hodgson | 1801 | 2003 | -202 |
| Corsoy | 1754 | 1761 | - 7 |
| Harcor | 1888 | 1878 | + 13 |
| Wells | 2305 | 1935 | +370 |
| Wayne | 2097 | 2023 | + 74 |
| Calland | 1956 | 2097 | -141 |
| | | L.S.D.(.05)= | 418ns |
| | | C.V.= | 11.7% |

*Each cultivar received a total of 790 kg/ha of foliar fertilizer. This total amount was divided among three equal applications made at growth stages R5, R6, and R7.

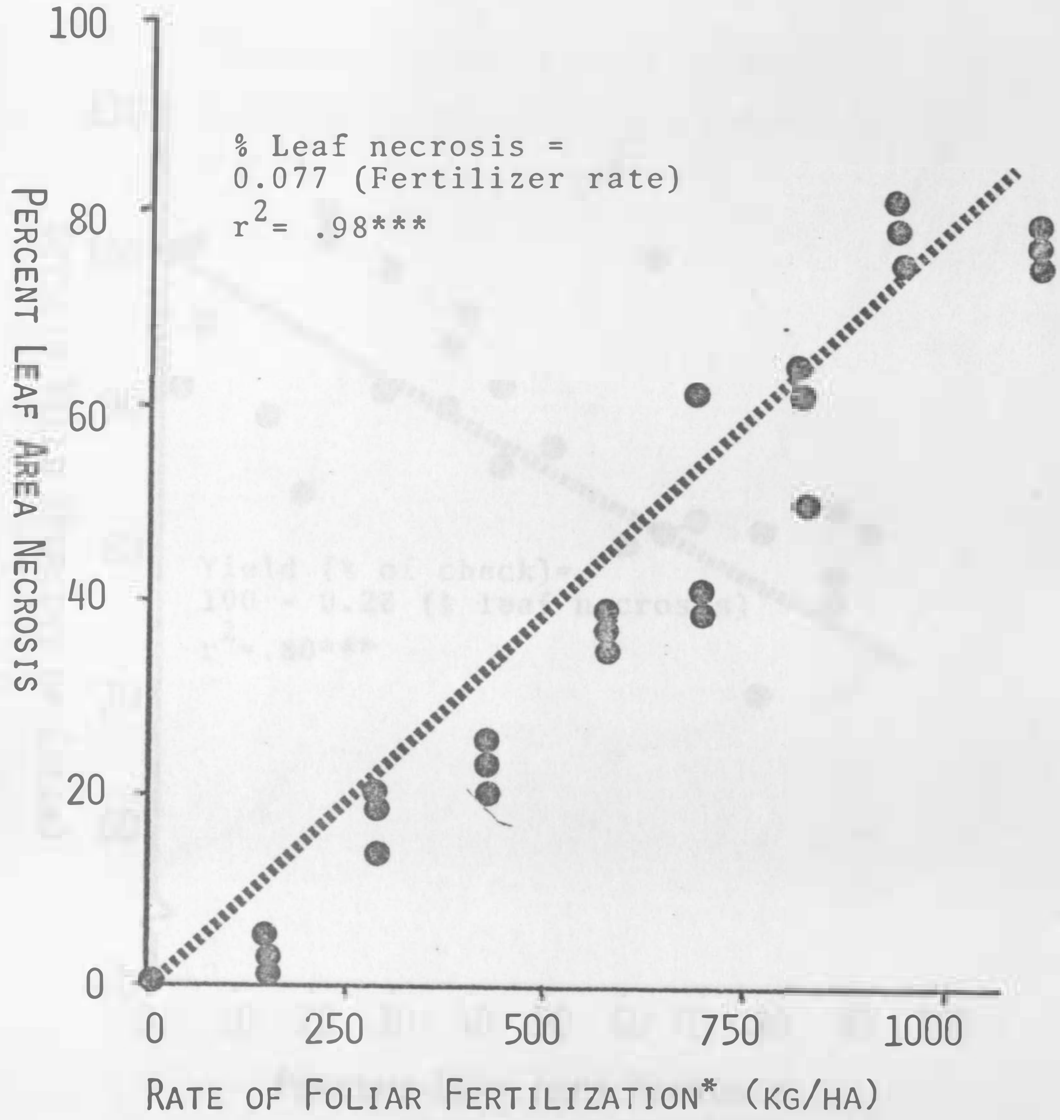
Leaf necrosis was negligible in experiment 77-7. The fertilized foliage of two cultivars, Calland and Wayne, exhibited a darker green color later into the growing season than the untreated checks of the same cultivars.

Leaf Necrosis Experiments of 1977

The effect of different rates of foliar fertilizer on leaf necrosis in experiment 77-2 (Agronomy Farm) is illustrated in Figure 1. A significant linear relationship exist ($R^2$=.98) between the rate of fertilizer application and leaf necrosis. There is little difference between the amount of leaf necrosis produced at the highest two fertilizer rates, an indication that the curve is beginning to level off at 80% leaf necrosis. This indicates that leaf damage had reached a maximum.

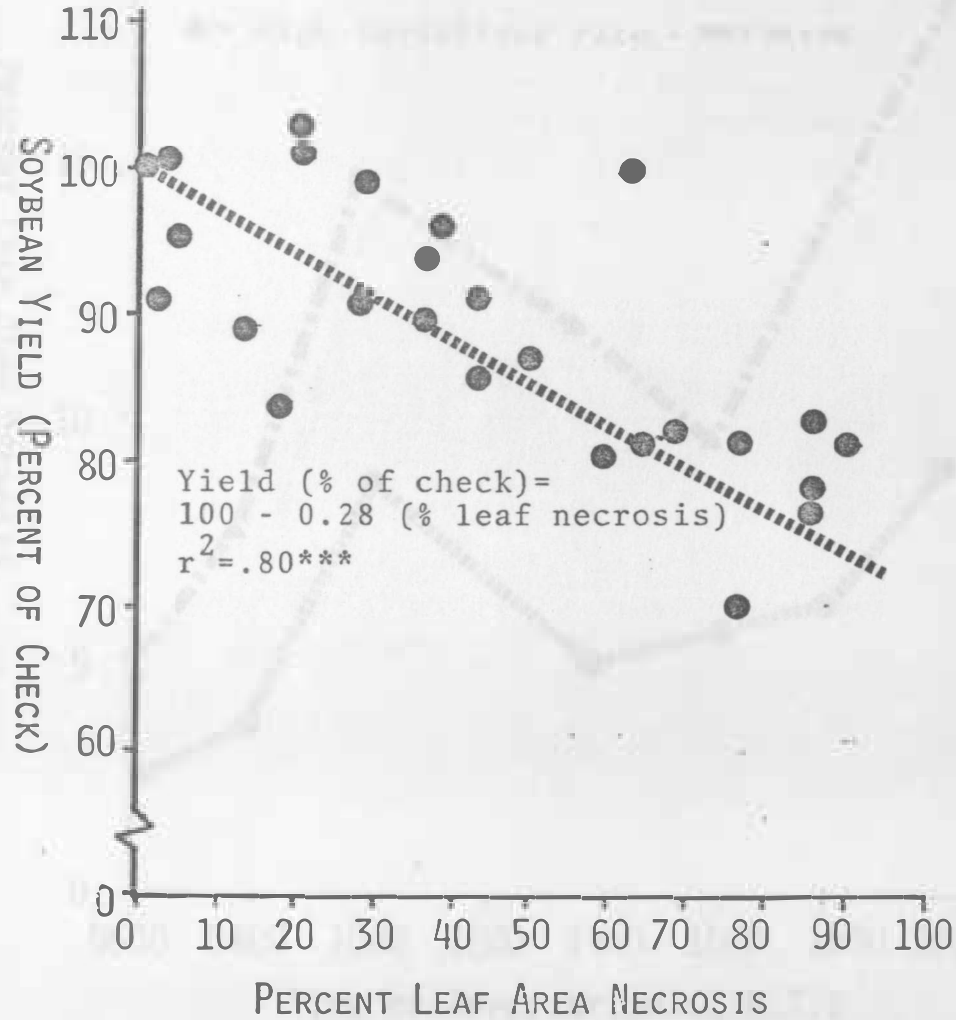
There was a significant ($R^2$=.80) negative correlation between leaf necrosis and soybean yield (Figure 2). Yields were significantly depressed at the .01 level (Table 10). Yields 8.6% lower than the check were considered to be significantly lower than the check at the .01 level. This correlates to approximately 30% leaf necrosis.

The relationship between the hour of fertilizer application and leaf necrosis in experiment 77-3 (Agronomy Farm) is presented in Figure 3 for 10 August 1977, and Figure 4 for 11 August 1977. Climatic data and leaf burn for these two days are documented in Appendix Table D. Both Figure 3 and Figure 4 indicate low levels of leaf necrosis at 0600 and 0800 C.D.T., and a peak of necrosis




*Fertilizer analysis: 10% N, 1% P, 3% K, 0.6% S.
***Independent variable significant at .001 level.

Figure 1. Relationship between foliar fertilizer rate and leaf necrosis, Brookings County, 1977.




***Independent variable significant at the .001 level.

Figure 2. Relationship between leaf necrosis and soybean yield, Brookings County, 1977.

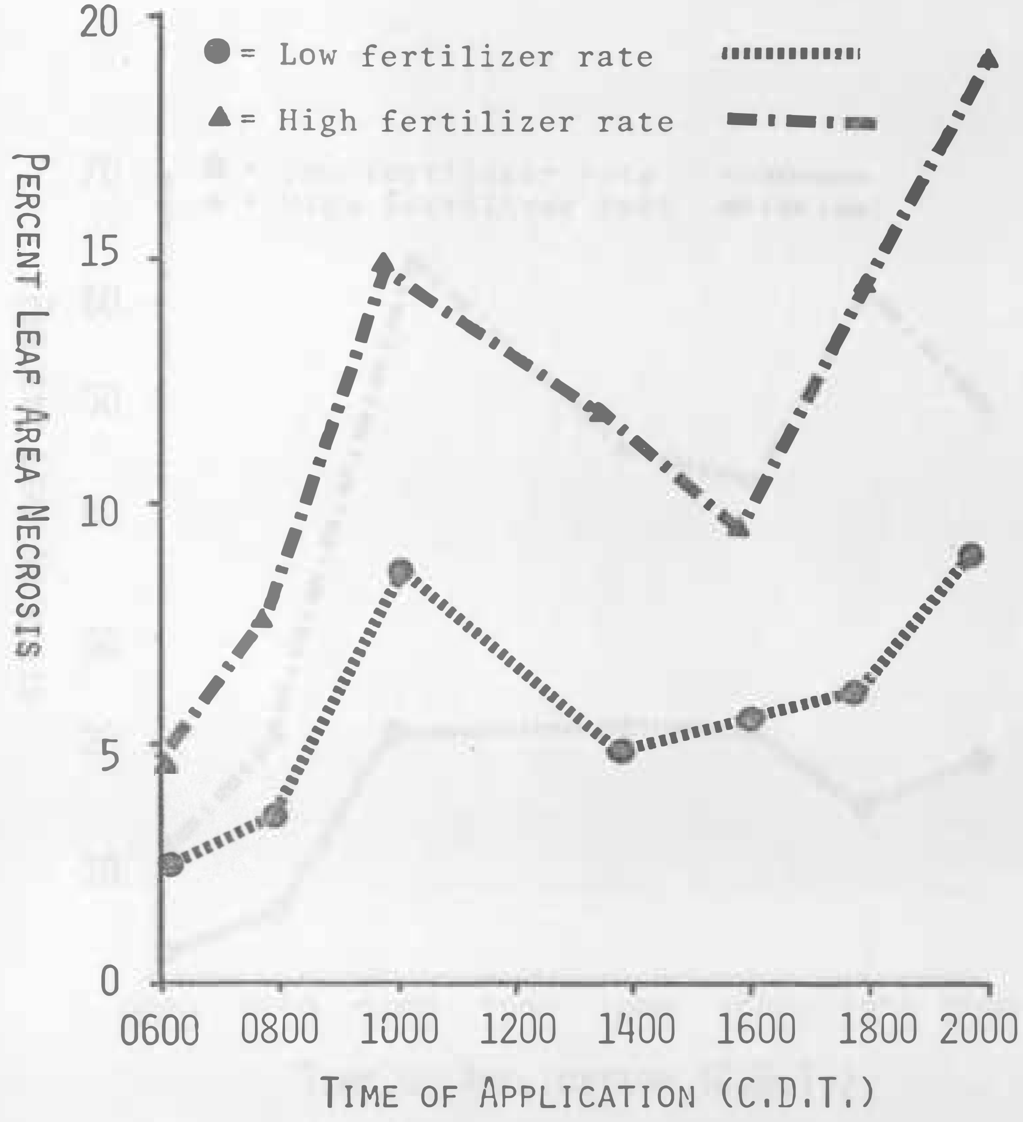



Figure 3. Relationship between time of foliar fertilizer application and leaf necrosis, 10 August 1977, Brookings County.

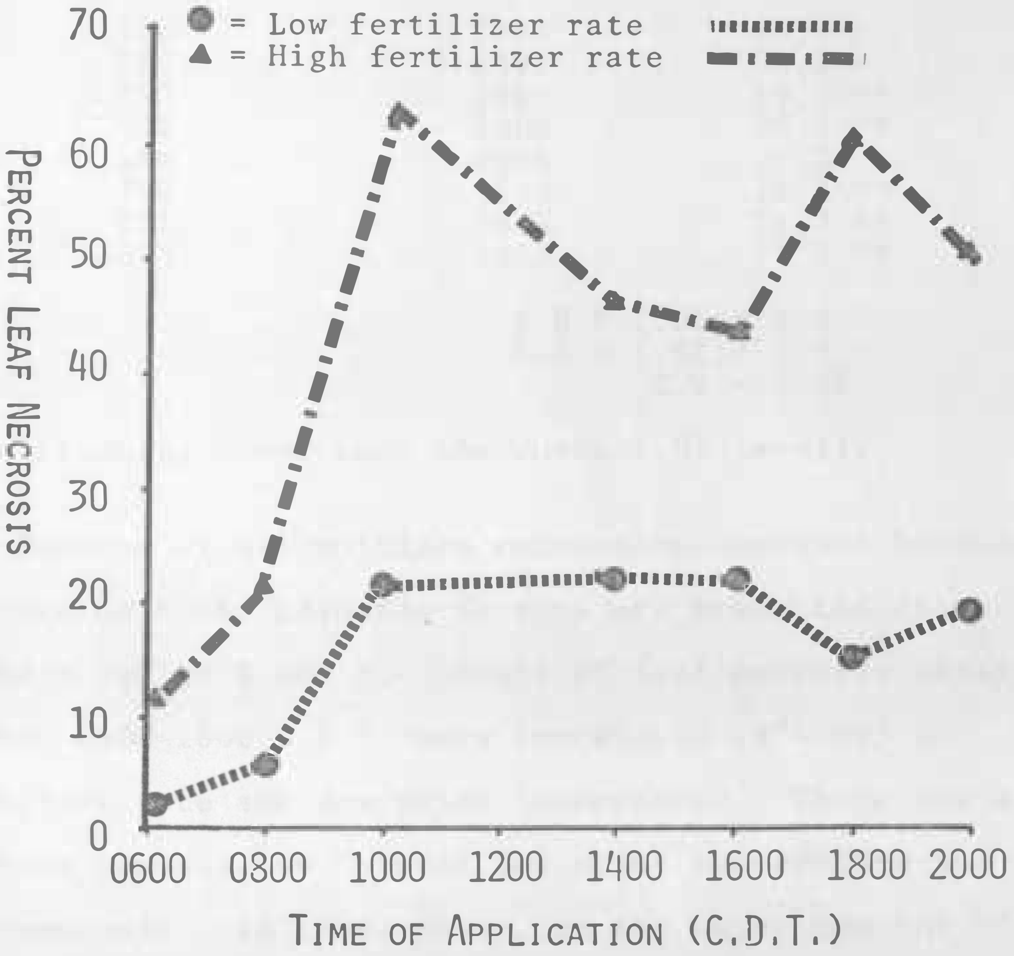



Figure 4. Relationship between time of foliar fertilizer application and leaf necrosis, 11 August 1977, Brookings County.

Table 10. Effect of foliar fertilization on soybean yields, Brookings County, 1977.

| Rate of Foliar Fertilizer Applied at Growth Stage: R5 | Soybean Yield | |
|---|---|---|
| (kg/ha) | (kg/ha) | (% of check yield) |
| 132 | 2184 | 95.0 |
| 263 | 2197 | 99.1 |
| 395 | 2117 | 89.5 ** |
| 526 | 2009 | 88.7 ** |
| 658 | 2043 | 96.2 |
| 790 | 1734 | 78.2 ** |
| 921 | 1687 | 78.7 ** |
| 1053 | 1646 | 71.2 ** |
| | L.S.D.(.05)= | 6.0 |
| | L.S.D.(.01)= | 8.6 |
| | C.V.= | 9.0% |

*Significantly lower than the check (.01 level).

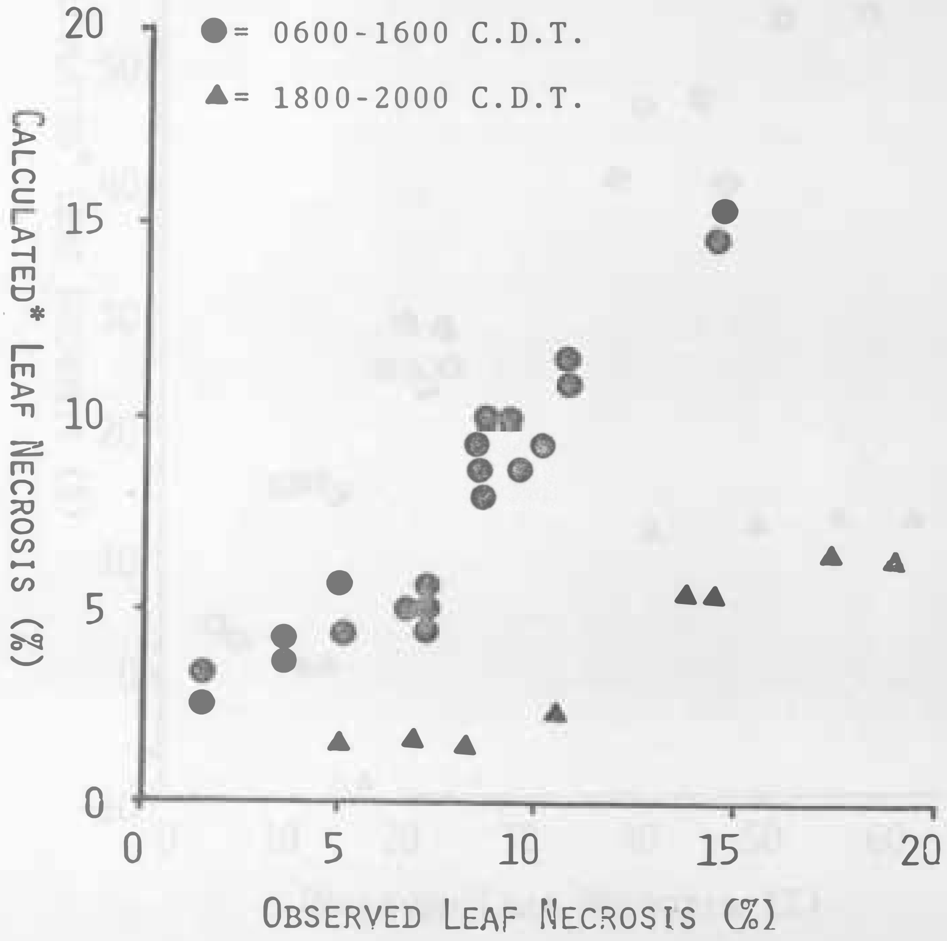
Results of all multiple regression analyses between leaf necrosis and climatic factors are presented in Appendix Tables E and F. Levels of leaf necrosis obtained between 0600-1600 C.D.T. were correlated ($R^2$=.90) to fertilizer rate and dew point temperature. There was a negative correlation between dew point temperature and leaf necrosis. In other words, as the water content of the air increased, the dew point temperature increased, and leaf necrosis decreased. Other climatic factors were not significant in predicting leaf necrosis during this time period.

Climatic conditions during 10 August 1977 were as follows: the sun was unobstructed by clouds from sunrise to 1100 C.D.T., at which time the sun was obstructed by a low ceiling of clouds. The relative humidity began to rise at 1100 C.D.T., and the cloud cover began to break up at sunset. Air temperature was relatively constant from 1000 to 1800 C.D.T.

Levels of leaf necrosis obtained at 1800 and 2000 C.D.T. on 10 August were more severe than was expected from equations derived using data from 0600 to 1600 C.D.T. (Figure 5).

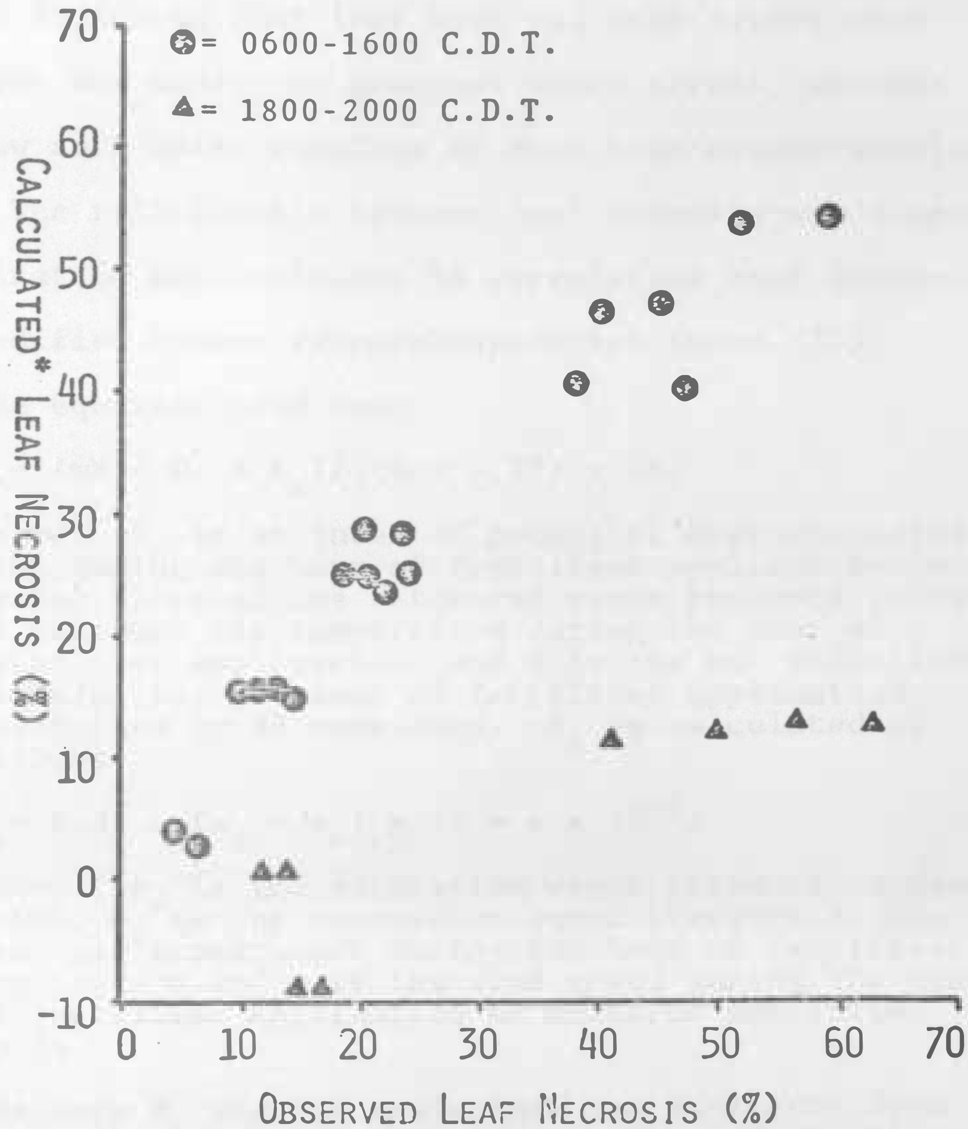
Leaf necrosis obtained between 0600-1600 C.D.T. on 11 August 1977 was correlated ($R^2$=.88) to fertilizer rate, solar radiation, and dew point temperature. There was virtually no cloud cover on 11 August. Data from 1800-2000 C.D.T. on 11 August did not fit the relationships between leaf burn and climatic variables determined from data from 0600-1600 C.D.T. on the same day (Figure 6). More research is needed to determine why leaf necrosis from late afternoon applications does not follow the same trends as leaf necrosis obtained from applications made earlier in the same day.

The effect of certain climatic variables on leaf necrosis was not constant from day to day. An index that would explain the variation in leaf necrosis on both 10 and 11 August would be helpful in understanding the influence of climate on foliar fertilizer-induced leaf necrosis.




*Equation used: % Necrosis= 64.3 + 0.017(Fertilizer rate) - 2.70 (Dew Point Temperature)

Figure 5. Relationship between observed and calculated leaf necrosis, 10 August 1977. Brookings County.




*Equation used: % Burn= -153.82 + 0.50 (Solar Radiation) + 0.0845 (Rate) + 5.29 (Dew Point Temp.)

Figure 6. Relationship between observed and calculated leaf necrosis, 11 August 1977, Brookings County.

Field notes taken during the 1976 and 1977 growing seasons indicated that leaf burn was most severe when the plant was under the greatest water stress, whether from low soil water supplies or from high evapotranspiration. The relationship between leaf necrosis and evapotranspiration was evaluated by correlating leaf necrosis to a modified Penman evapotranspiration index (25).

The equation used was:

$$E_o = (mH + 0.28\ E_a)/((m + 0.27) \times 24)$$

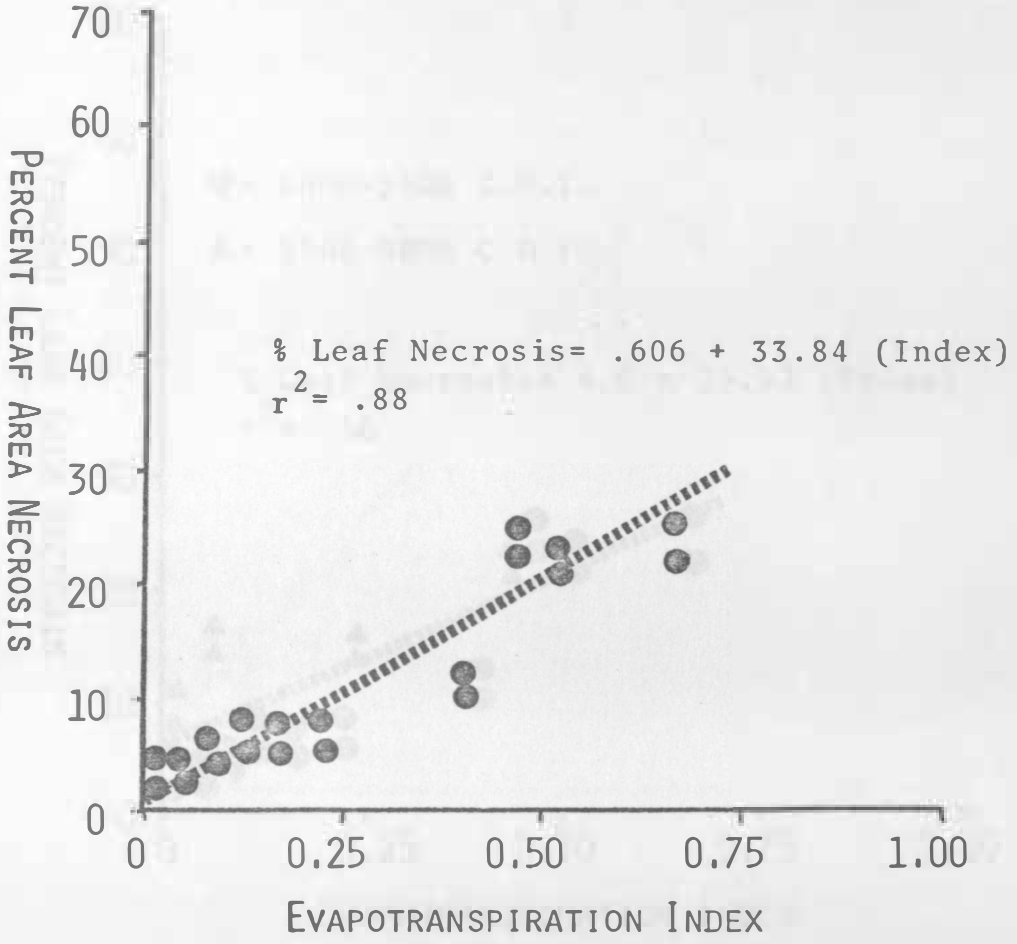
Where: $E_o$ is an index of potential evapotranspiration during the hour of fertilizer application, m is the slope of the saturated vapor pressure curve at the mean air temperature during the hour of fertilizer application, and H is the net radiation in mm/hr for the hour of fertilizer application, multiplied by 24 hours/day. $E_a$ is calculated as follows:

$$E_a = 0.35 \times (e_d - e_a) \times (1 + u \times 10^{-2})$$

Where: $e_d$ is the saturation vapor pressure at dew point, $e_a$ is the saturation vapor pressure at the mean air temperature during the hour of fertilizer application and u is the wind speed during the hour of fertilizer application in miles/hr multiplied by 24.

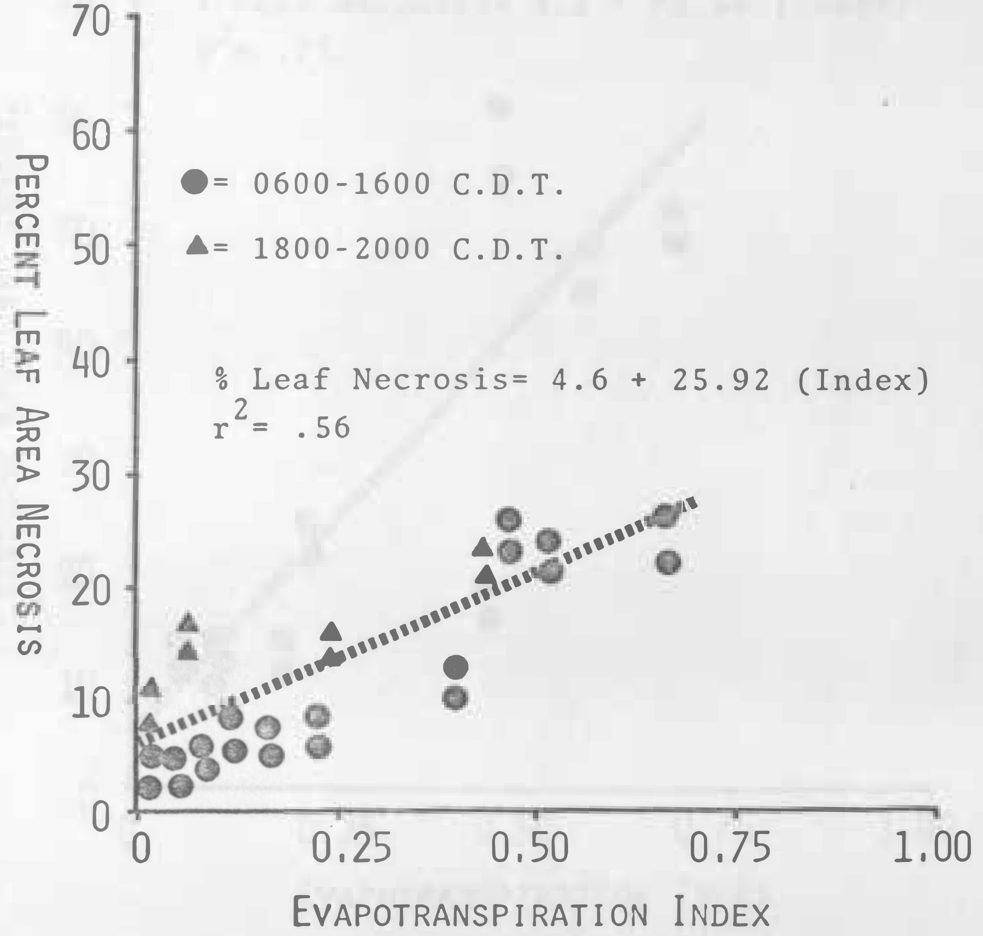
The term H, the net radiation, was estimated from equations derived by Shaw (29), and from solar radiation data collected near the experimental area.

The relationships between an index of potential evapotranspiration and leaf necrosis are presented in Figures 7-10. Changes in the index explain a significant proportion of the variation in leaf necrosis when data



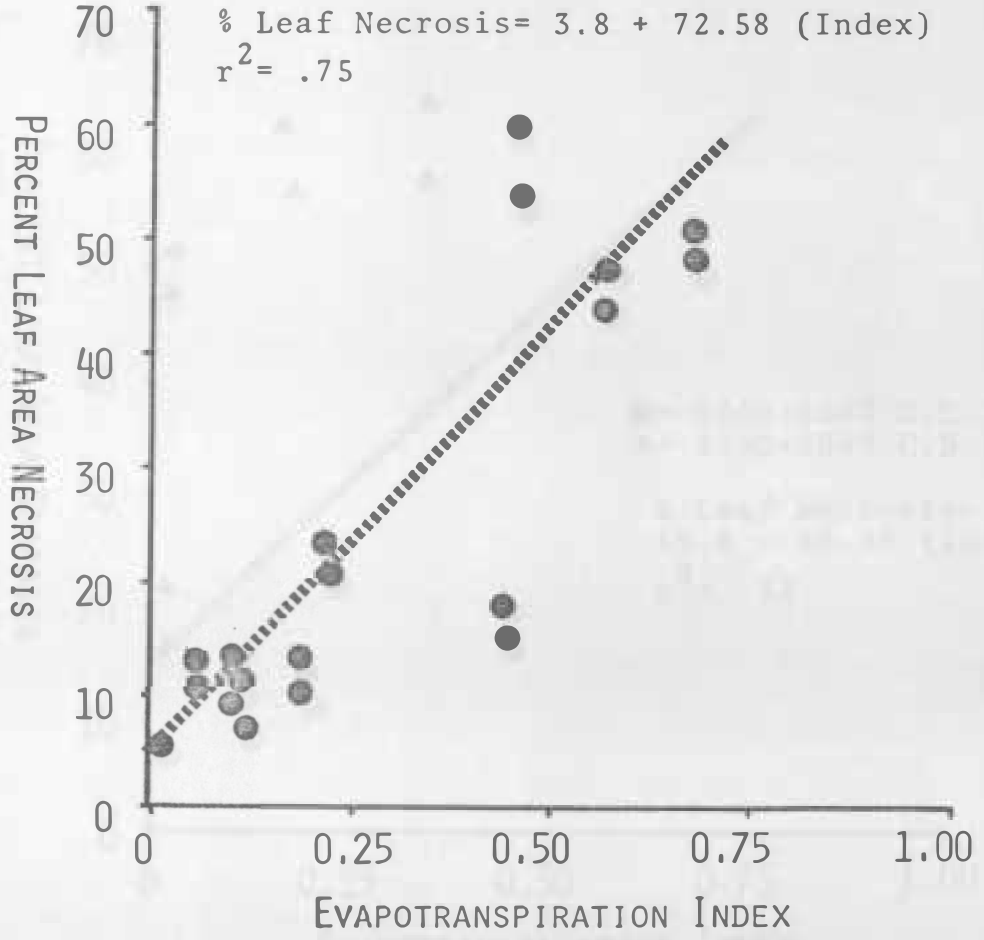

Fertilizer rate: 263 kg/ha of 10% N, 1% P, 3% K, 0.6% S.

Figure 7. Relationship between an index of evapotranspiration and foliar fertilizer-induced leaf necrosis, 0600-1600 C.D.T., 10 and 11 August 1977, Brookings County.



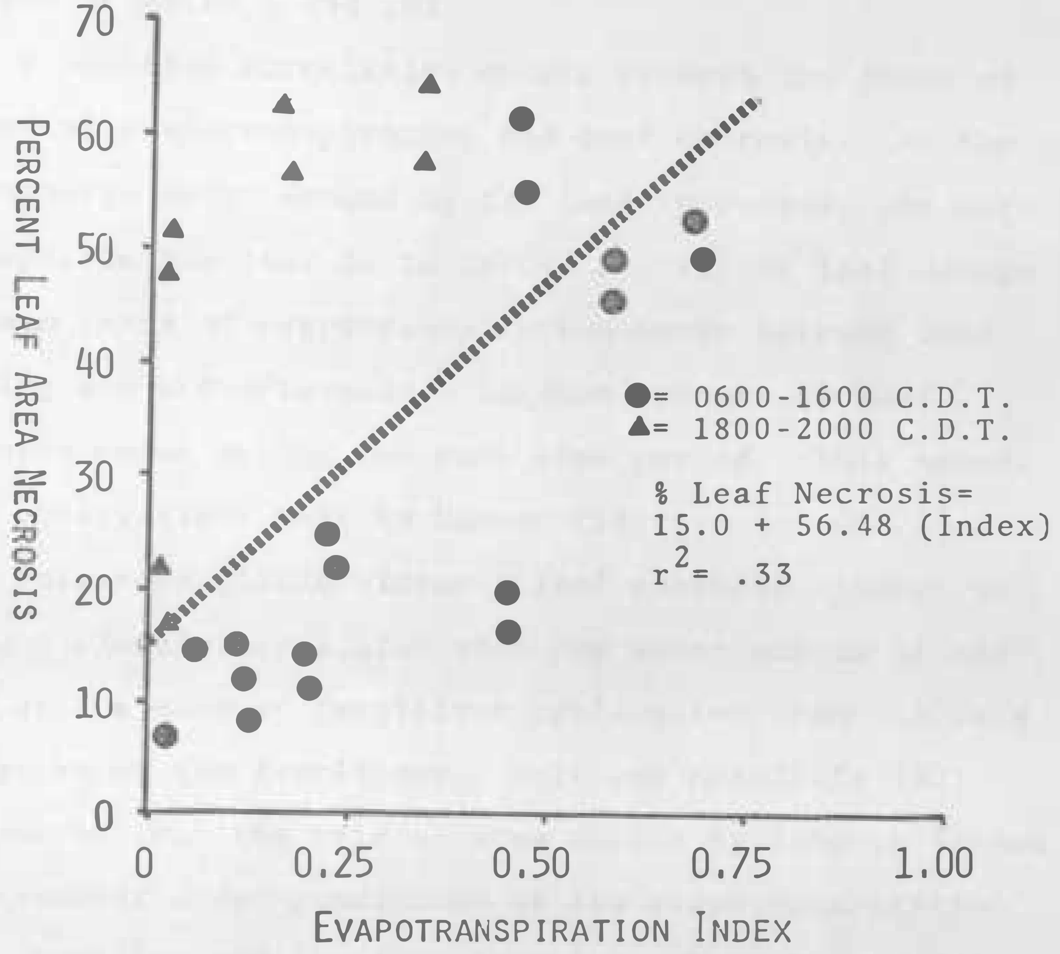

Fertilizer rate: 263 kg/ha of 10% N, 1% P, 3% K, 0.6% S.

Figure 8. Relationship between an index of evapotranspiration and foliar fertilizer-induced leaf necrosis, 10 and 11 August 1977, Brookings County.




Fertilizer rate: 526 kg/ha of 10% N, 1% P, 3% K, 0.6% S.

Figure 9. Relationship between an index of evapotranspiration and foliar fertilizer-induced leaf necrosis, 0600-1600 C.D.T., 10 and 11 August 1977, Brookings County.




Fertilizer rate was: 526 kg/ha of 10% N, 1% P, 3% K, 0.6% S.

Figure 10. Relationship between an index of evapotranspiration and foliar fertilizer-induced leaf necrosis, 10 and 11 August 1977, Brookings, County.

from 1800 and 2000 C.D.T. are not included in the regressions (Figures 7 and 9). Inclusion of data points from 1800 and 2000 C.D.T. lowers the coefficients of determination, but the regression coefficients are not greatly changed (Figures 8 and 10).

A positive correlation exists between the index of potential evapotranspiration and leaf necrosis. As the atmospheric water demand on the leaf increases, the more susceptible the leaf is to foliar fertilizer leaf damage. Maximum rates of evapotranspiration occur between late morning and mid-afternoon. Maximum amounts of leaf necrosis occur during the same time period. This agrees with observations made by Hanway (18).

Foliar fertilizer-induced leaf necrosis appears to be more closely correlated with the water status of the leaf at the time of fertilizer application than the rate of uptake of the fertilizer. Volk and McAuliffe (37) discovered that the rate of urea uptake by tobacco leaves was greatest under conditions of low evapotranspiration (high humidity and low temperatures). More research is needed to investigate the relationship between foliar fertilizer-induced leaf necrosis and weather conditions.

# SUMMARY AND CONCLUSIONS

Eleven field experiments involving foliar fertilization of soybeans with N, P, K, and S solutions were used to accomplish three objectives. The major objective of nine of the eleven experiments was to determine if foliar fertilization of soybeans would increase seed yields. One experiment was designed to evaluate the effect of foliar fertilizer-induced leaf necrosis on seed yield. The final objective was to investigate the relationship between climatic factors and leaf necrosis.

Soybean yields were not influenced by foliar fertilization in seven out of nine experiments. Significant yield depressions were noted in one experiment. A small yield increase (215 kg/ha or 3.2 bu/ac), significant at the .05 level, was observed in one trial. The large yield increases from foliar fertilization observed in Iowa could not be duplicated in South Dakota. It is concluded that foliar fertilization of soybeans with present techniques can not be recommended under South Dakota growing conditions.

Leaf necrosis was a problem associated with foliar fertilization. Sucrose was effective in reducing leaf necrosis in one experiment. There was no yield benefit from the use of sucrose additives.

Foliar fertilizer-induced leaf necrosis was significantly correlated with soybean yield decreases. Leaf necrosis involving more than 30% of the leaf area was correlated to statistically significant yield depressions at the .01 level.

The amount of leaf necrosis produced by foliar fertilization was related to the climatic conditions at the time of fertilizer application. Dew point temperature, air temperature, and solar radiation were independent variables which explained significant proportions of the variation in leaf burn. The role of each climatic variable changed from day to day.

Significant positive correlations were observed between leaf necrosis and a Penman potential evapotranspiration index, illustrating the influence of leaf water status on the susceptibility of the leaf to foliar fertilizer-induced leaf necrosis. More research is needed to study the interactions between weather conditions and foliar fertilizer-induced leaf necrosis.

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Appendix Table A. Stage of Growth Descriptions for Soybeans.

| Stage Number | Description |
| --- | --- |
| R4 | Pod 2 cm long at one of the four uppermost nodes. |
| R5 | Beans can be felt when the pod is squeezed at one of the four uppermost nodes. |
| R6 | Pod containing full size green beans at one of the four uppermost nodes. |
| R7 | Pods yellowing; 50% of leaves yellowing. Physiological maturity. |
| R8 | 95% of pods brown. Harvest maturity. |

Appendix Table B. Climatic Data from the Foliar Fertilization Experiments

| Location | Year | Data | May | June | July | Aug. | Sept | Oct | Total |
|---|---|---|---|---|---|---|---|---|---|
| Redfield 10 km E | 1976 | Precip. (mm) | 13.5 | 94.5 | 35.8 | 13.7 | 44.7 | - | 202.2 |
| | | Mean Temp, (°C) | 13 | 21 | 24 | 24 | 16 | - | |
| | | Days 32°C + | 0 | 11 | 17 | 18 | .5 | - | |
| | | First Frost Date | | | | | 23 | | |
| | | Irrigation (Exp. 76-2) | | | 76 | | | | 76 |
| Centerville 10 km SE | 1977 | Precip. (mm) | 49.8 | 33.3 | 45.4 | 26.7 | 29.0 | - | 184.2 |
| | | Mean Temp, (°C) | 19 | 21 | 24 | 20 | 17 | | |
| | | Days 32°C + | 1 | 8 | 15 | 17 | 4 | | |
| | | First Frost Date | | | | | 30 | | |
| | | Irrigation (Exp. 76-4) | | | 76 | 76 | | | |
| Centerville 10 km SE | 1977 | Precip. (mm) | 81.8 | 87.9 | 98.0 | 66.0 | 101.6 | 47.8 | 483.1 |
| | | Mean Temp, (°C) | 19 | 21 | 24 | 20 | 17 | - | |
| | | Days 32°C + | 0 | 4 | 11 | 2 | 1 | | |
| | | First Frost Date | | | | | | 6 | |
| Brookings 3 km NE | 1977 | Precip. (mm) | 37.6 | 185.7 | 44.2 | 127.8 | 94.0 | 59.4 | 548.7 |
| | | Mean Temp, (°C) | 18 | 19 | 22 | 17 | 15 | 7 | |
| | | Days 32°C + | 1 | 2 | 8 | 0 | 0 | | |
| | | First Frost Date | | | | | | 3 | |

Appendix Table C. Some Characteristics of the Foliar Fertilizer Experiments.

| Experiment Number | Purpose of Experiment | Experiment Design* | Replications | Application Dates |
|---|---|---|---|---|
| 76-1 | Effect of foliar fertilization on soybean yield | RCB | 4 | 28 August 1976<br>2 September 1976 |
| 76-2 | Effect of foliar fertilization on soybean yield | RCB | 10 | 28 August 1976<br>2 September 1976 |
| 76-3 | Effect of foliar fertilization on soybean yield | RCB | 4 | 13 August 1976<br>20 August 1976<br>24 August 1976<br>31 August 1976 |
| 76-4 | Effect of foliar fertilization on soybean yield | RCB | 4 | 13 August 1976<br>20 August 1976<br>24 August 1976<br>31 August 1976 |
| 77-1 | Effect of foliar fertilizer and sucrose on soybeans | 3 x 2 FACT | 6 | 11 August 1977<br>24 August 1977 |
| 77-2 | Effect of leaf necrosis on soybean yield | SP | 3 | 11 August 1977 |
| 77-3 | Effect of climate on leaf necrosis | SP | 3 | 10 August 1977<br>11 August 1977 |
| 77-4 | Effect of foliar fert. and sucrose on soybean yield | 3 x 3 FACT | 4 | 17 August 1977<br>30 August 1977 |

Appendix Table C, continued.

| Experiment Number | Purpose of Experiment | Experiment Design* | Replications | Application Dates |
|---|---|---|---|---|
| 77-5 | Effect of foliar fertilization on soybean yield | RCB | 12 | 16 August 1977<br>30 August 1977 |
| 77-6 | Effect of three foliar fertilizer solutions on soybean yield | RCB | 3 | 16 August 1977<br>30 August 1977 |
| 77-7 | Effect of foliar fert. on eight cultivars | SP | 3 | Many application dates due to varied cultivar maturities |

*RCB= Randomized Complete Block
FACT= Complete Factorial Arranged in Blocks
SP= Split Plot Design

Appendix Table D. Leaf Necrosis Data and Climate Data on 10 and 11 August 1977.

| | | Leaf Necrosis Data | | | | Climate Data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 264 (kg/ha) of Foliar Fert. | | 528 (kg/ha) of Foliar Fert. | | | | | | |
| Date | Time (C.D.T.) | Sub. 1 (%) | Sub. 2 (%) | Sub. 1 (%) | Sub. 2 (%) | Air Temp. (°C) | Dew Point Temp. (°C) | Wind Speed (mph) | Solar Rad. (cal/cm$^2$) | Evapo-Transpir. Index - |
| 10 Aug. | 0600 | 2.8 | 2.7 | 5.2 | 4.4 | 13.0 | 7.2 | 13 | 1.2 | .072 |
| | 0800 | 3.7 | 3.2 | 7.1 | 8.7 | 17.2 | 6.4 | 5 | 21.6 | 3.69 |
| | 1000 | 10.3 | 8.6 | 15.0 | 14.3 | 18.1 | 4.2 | 8 | 48.0 | 8.98 |
| | 1400 | 3.6 | 4.5 | 11.7 | 11.8 | 17.2 | 5.6 | 13 | 13.2 | 1.94 |
| | 1600 | 4.1 | 6.0 | 8.3 | 10.0 | 16.1 | 6.1 | 1 | 19.2 | 3.16 |
| | 1800 | 5.6 | 7.0 | 14.0 | 14.1 | 15.6 | 6.4 | 5 | 14.4 | 2.32 |
| | 2000 | 10.2 | 7.7 | 17.4 | 22.0 | 11.9 | 6.6 | 3 | 3.6 | 0.39 |
| 11 Aug. | 0600 | 3.0 | 3.1 | 12.1 | 10.1 | 9.2 | 6.1 | 6 | 1.2 | 0.74 |
| | 0800 | 4.7 | 4.3 | 24.1 | 21.8 | 15.8 | 5.8 | 11 | 21.6 | 5.01 |
| | 1000 | 23.8 | 21.5 | 57.4 | 63.4 | 19.4 | 8.1 | 16 | 49.2 | 11.88 |
| | 1400 | 19.7 | 23.9 | 47.9 | 43.9 | 23.9 | 5.8 | 0 | 63.6 | 16.19 |
| | 1600 | 21.0 | 19.9 | 40.5 | 47.4 | 23.3 | 5.6 | 0 | 50.4 | 12.66 |
| | 1800 | 15.2 | 12.4 | 65.4 | 59.5 | 19.4 | 5.0 | 0 | 24.0 | 5.62 |
| | 2000 | 17.0 | 16.8 | 52.7 | 41.7 | 14.7 | 5.0 | 0 | 1.2 | 0.35 |

Appendix Table E. Variables Used in Regression Analyses

| Variable Name | Description of Variable | Units |
|---|---|---|
| BURN | Leaf necrosis on a random sample of leaves from the uppermost four nodes of the soybean plant | % |
| DP | Dew Point Temperature | °C |
| ET | A modified Penman index of evapotranspiration | - |
| RATE | Foliar Fertilizer Rate | kg/ha |
| SOLAR | Incoming solar radiation | $cal/cm^2$ |
| TEMP | Air Temperature | °C |

Appendix Table F. Results of Regression Analyses for Predicting Percent Leaf Necrosis Induced by Foliar Fertilization.

| Time Period Under Analysis | Independent Variables | Significance of Independent Variables | Regression Equation | $R^2$ |
|---|---|---|---|---|
| 0600-2000 C.D.T.<br>10 & 11 Aug. 1977 | TEMP<br>RATE | .001 | BURN= -79.99 + 2.12 TEMP + 0.062 RATE | .45 |
| 0600-2000 C.D.T.<br>10 & 11 Aug. 1977 | SOLAR<br>RATE<br>DP | .001<br>.001<br>.001 | BURN= -158.74 + .57 SOLAR + 0.051 RATE + 1.03 DP | .76 |
| 0600-2000 C.D.T.<br>10 Aug. 1977 | RATE<br>DP<br>TEMP | .001<br>.10<br>.025 | BURN= 97.98 0.021 RATE - 2.65 DP - 1.01 TEMP | .51 |
| 0600-1600 C.D.T. | DP<br>RATE | .001<br>.001 | BURN= 64.31 - 2.71 DP + 0.18 RATE | .90 |
| 0600-2000 C.D.T.<br>11 Aug. 1977 | RATE<br>TEMP<br>SOLAR<br>DP | .001<br>.001<br>ns<br>.001 | BURN= -470.53 + 0.10 RATE + 6.53 TEMP - 1.10 SOLAR + 10.86 DP | .79 |
| 0600-1600 C.D.T.<br>11 Aug. 1977 | SOLAR<br>RATE<br>DP | .001<br>.001<br>.005 | BURN= -153.82 + 0.50 SOLAR + 0.84 RATE + 5.29 DP | .88 |

Appendix Table F. continued.

| Time Period Under Analysis | Independent Variables | Significance of Independent Variables | Regression Equation | $R^2$ |
|---|---|---|---|---|
| 0600-2000 C.D.T. 10 & 11 Aug. 1977 | ET<br>RATE | .001<br>.001 | BURN= -15.07 + 40.22 ET + 0.062 RATE | .45 |
| 0600-1600 C.D.T. 10 & 11 Aug. 1977 | ET<br>RATE | .001<br>.001 | BURN= 18.10 + 53.30 ET + 0.51 RATE | .72 |
| 0600-2000 C.D.T. 10 Aug. 1977 | RATE | .001 | BURN= -015 + 0.23 RATE | .37 |
| 0600-1600 C.D.T. 10 Aug. 1977 | RATE<br>ET | .001<br>.001 | BURN= -2.70 + 19.98 ET + 0.022 RATE | .79 |
| 0600-2000 C.D.T. 11 Aug. 1977 | RATE<br>ET | .001<br>.025 | BURN= -21.08 + 0.102 RATE + 27.42 ET | .59 |
| 0600-1600 C.D.T. 11 Aug. 1977 | ET<br>RATE | .001<br>.001 | BURN= -27.39 + 50.33 ET + 0.084 RATE | .80 |